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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 415

CLIMBING EFFICIENCY OF AIRCRAFT

By C. C. Walker

From "Flight," January 27, 1927

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 415.

CLIMBING EFFICIENCY OF AIRCRAFT.*

By C. C. Walker.

It is often said that no great aerodynamic improvements are in sight and that the efficiency of aircraft as transport vehicles is only capable of ordinary steady development. While this is, no doubt, somewhere near the truth so far as aerodynamics are concerned, it is, perhaps, worth while to see what margin there may be for improvement without looking very far ahead or relying on the doubtful possibility of new discoveries.

The rate of climb at ground level is of obvious and vital importance in bombers and commercial airplanes, but less so for types which possess a great margin of power and have to develop their qualities at heights. Since the weight that can be transported is limited to that which can be safely taken off the ground, the efficiency in the climbing condition becomes important. It is quite common to find that only 50 per cent of the brake horsepower at maximum revolutions is being turned into useful work in this condition, and if an improvement in the efficiency of, say, 5 per cent could be secured, the improvement in climb would be much more than this owing to the fact that the power used in merely sustaining the airplane is

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constant and any increase in available power is a relatively large percentage of that used in actually climbing.

If the brake horsepower developed at maximum speed flying level is taken as the basis, it may be divided up as follows when climbing:

(1) Minimum horsepower required to sustain level flight.

(2) Horsepower returned as actual climb.

(3) Owing to the compromise between the aircraft and propeller curve, the best climbing speed is higher than that for minimum horsepower. The difference is lost work.

(4) The extra drag in the slip stream, or whatever may be included in this term. This is really an excess loss over that incurred at maximum speed.

(5) The horsepower lost by the propeller in turning brake horsepower into thrust horsepower.

(6) The horsepower lost (or rather, not used) by the engine losing revolutions when climbing.

It is best to regard Nos. 1 and 2 as useful work for the present purpose, as airplanes of different weight per horsepower can then be compared easily. As regards No. 4, it might be supposed that the same fraction of the thrust horsepower would be lost by the slip stream impinging on obstacles at all values of V/nD . This does not appear to be the case, and is probably due to the fact that the slip stream contracts more at climb than at speed.

Loss No. 5 is, of course, affected by the speed range of the airplane, since a propeller working at a much lower forward speed (climbing) than that for which it is designed, is correspondingly inefficient.

The figures given illustrate the sort of value which may be encountered in practice, and are taken from actual examples of modern aircraft.

Figure 1.— This shows that under 50 per cent of the maximum brake horsepower is made use of on the climb, and that the drop in revolutions accounts for 12.25 per cent, which is an unusually large amount compared with water-cooled engines. This figure is, of course, susceptible of considerable variation, as it depends on induction, heating, etc. In the case given, the engine is capable of functioning satisfactorily at heights and in low temperatures, and there is no doubt that when the cooling is relatively less, as in climbing near the ground, a smaller loss of revolutions could be secured by deliberately going out for it. It is probable that low-ceiling airplanes, such as heavy bombers or passenger carriers, require a special intake and induction system on air-cooled engines.

Figure 2.— This illustrates a case in which everything is favorable to efficiency on the climb— the speed range is low owing to the weight per horsepower being high and, therefore, the propeller is still working under tolerable conditions on the climb.

The 2 : 1 gear reduction (the engine is a 90 R.A.F.) not only permits a high propeller efficiency, but also sufficient diameter to keep the slip stream clear of obstruction even on the climb. The smaller drop in revolutions compared with Figure 1 is, of course, partly due to the smaller speed range, and any possible engine temperature effect can only be disentangled from propeller phenomena if a large number of tests are available. An examination of a great number of tests of De Havilland airplanes, extending over 11 years, shows that on the whole there is a much greater drop in power on the climb in air-cooled than in water-cooled engines.

Figure 3.— This figure relates to a water-cooled, ungeared outfit of fairly high speed range, and shows the inevitably bad propeller and slip conditions, which are, however, compensated to some extent by the small drop in revolutions. As the speed range of aircraft is increased, the need for the variable pitch propeller becomes more insistent, but if performance at great heights only is required, where the speed range is much contracted, this is not so much the case. Nevertheless it may be found that when operating from temporary war airports exceptionally good "take-off" and "climb" qualities will always be useful.

A word is necessary, perhaps, as to how the "horsepower" required, shown in these curves, is arrived at. There are, of course, many different ways of doing this, but the following

seems to be more free from uncertainties than others. The level speed and rate of climb are carefully ascertained for ground level, and it is then assumed that the propeller efficiency at speed and drag of the wing surface alone is known (there is much full scale, theoretical and other evidence on this point). The intercept between the wing and total horsepower is then considered to vary as the cube of the speed. The horsepower available curve is put in in the usual way. It will then be found that the measured climb is less than would be indicated by the intercept between these curves and the difference is debited to the propeller as "slip loss" or rather, additional losses from obstructions over and above those incurred at speed. This somewhat crude method of displaying what is measured in routine tests has certain advantages when comparing many different results.

There has always been some discussion as to whether engine power varies more nearly as the pressure or the density. So far as water-cooled engines are concerned, any one dealing with a large number of tests of aircraft using the same engine, must have noticed that the density theory gives somewhat inconsistent results in varying temperatures, and this seems to be generally admitted. It also seems inherently likely that in a water-jacketed induction system and cylinder the amount of charge will be fairly independent of the atmospheric temperature; in other words, that the (indicated) horsepower will vary

as the pressure. As regards air-cooled engines, while the writer has had no opportunity as yet of sifting available data, it seems equally likely that atmospheric temperature will affect the amount of charge by affecting the temperature of the cylinder walls; in other words, that the pressure law will not be applicable. If this is the case, there will be a difficulty in knowing what brake horsepower is actually being obtained under varying conditions of flight. Thus, if we suppose that on some particular day in level flight at maximum speed, the engine temperature is the same as during the bench test on which the power curve was obtained, then if the airplane is climbed at about half the forward speed the engine must be warmer than on the level test and the power output less than on the bench at the same revolutions.

Some of the losses of power considered above may seem to be rather small, but the climbing qualities of aircraft are sensitive to small variations of power and the commercial qualities are sensitive to the climbing qualities, so there is no doubt as to the commercial, and in many cases military, importance of these losses.

The advent of either a variable pitch propeller or a two-speed gear will get rid of loss numbers 3 and 6 in the figures above, and produce the result shown in Figure 4, where it is applied to and superposed upon the Figure 2 results. In this case, the use of a water-cooled engine is presupposed, or

alternatively, that there is no temperature-effect loss of revolutions if it is air-cooled.

Now the conditions shown in Figures 1 and 3 are not exceptionally bad, and as the tendency to boost power by increasing revolutions proceeds, the climbing efficiency there shown tends to become more common and even worse. It may be repeated that the results shown with the antique power plant of Figure 2 are obtained on an existing airplane and are due only to decent propeller conditions, and the further improvement of Figure 4 is obtained without looking very far into the future.

There is a tendency in some quarters to view propeller performance only in the speed condition, and this may be responsible for the prevailing inadequate slip-stream areas.

We will now look in a quantitative way at three of the cases taken above and will illustrate them by applying the three efficiencies of Figures 1, 2, and 4, to an imaginary commercial airplane of characteristics suited to the Figure 1 power plant.

Figure 5 shows the power available in each case on an airplane having a power and surface loading of about 14.75 and 10, respectively, and carrying about $4\frac{1}{2}$ pounds per horsepower of paying load with the power plant of Figure 1, i.e., an air-cooled, ungeared, radial engine, of fairly high revolutions.

The curve marked 2 relates to the engine with a 2 : 1 reduction gear, and that marked 4, to the same with a variable

pitch propeller.

The rates of climb in the three cases are 516 : 735 : and 920 ft./min.

There are many different ways of looking at the advantage gained between the two extreme cases: it is possible to retain the advantage of a large reserve horsepower, to install an engine of 75 per cent of the power and carry more load (at a rather lower speed), or to increase the total weight and retain the original climb and "get off."

Space will not permit of going into these cases in detail, nor of discussing the advisability or otherwise/^{of} adding to mechanical complications, but when it is seen that the imaginary airplane considered above (which may be taken as a limiting "get off" case) could now get off with the same facility but with nearly 20 lb./HP. total weight, a figure which would mean that in some cases the paying load per horsepower could be doubled, the magnitude of the losses frequently incurred now can be easily realized.

It is evident that from the purely aerodynamic point of view it would pay to have the propeller revolutions so low that the efficiency at speed would begin to suffer somewhat but, of course, there are many practical considerations in these things, and the object of this report was to indicate that we frequently only make use of 50 per cent of the maximum brake

horsepower of the engine in taking a load off the ground, that this loss is not inevitable, and the effort to get engines of low weight per horsepower by boosting revolutions is very little use to bombers and commercial airplanes.

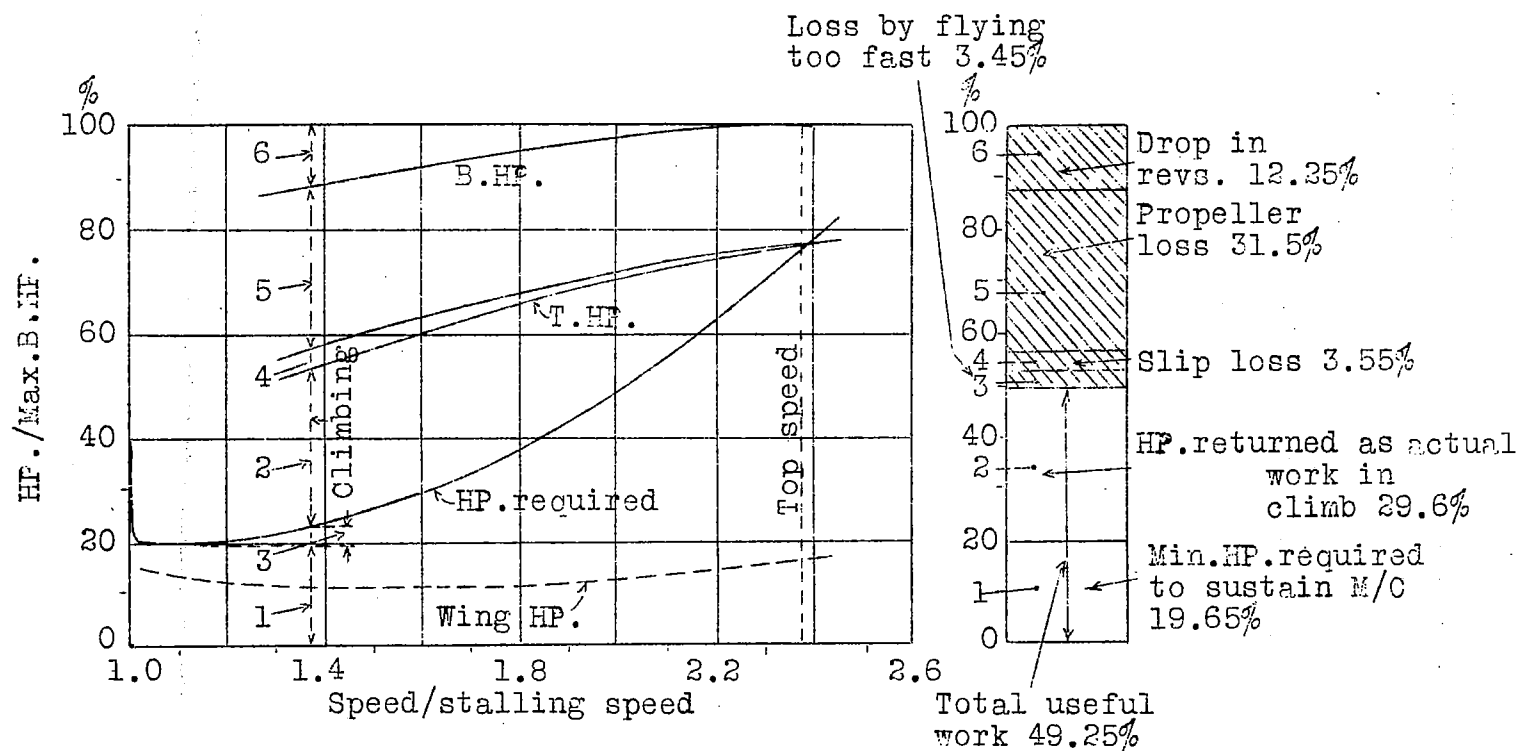


Fig.1 HP. speed curves & power balance sheet, single engine tractor biplane(land M/C)with radial aircooled ungeared engine.

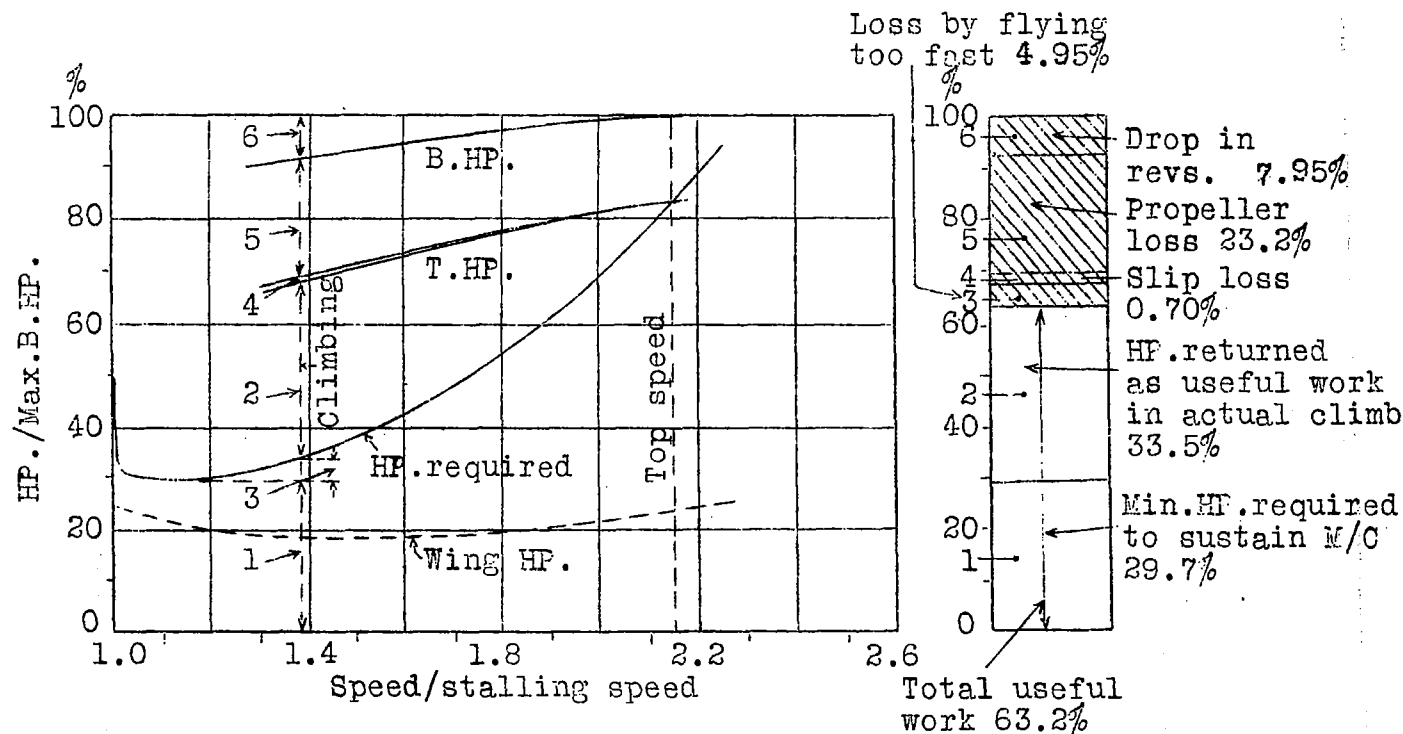


Fig. 2 HP speed curves & power balance sheet, single engine tractor biplane (land M/C) with vee air-cooled geared engine.

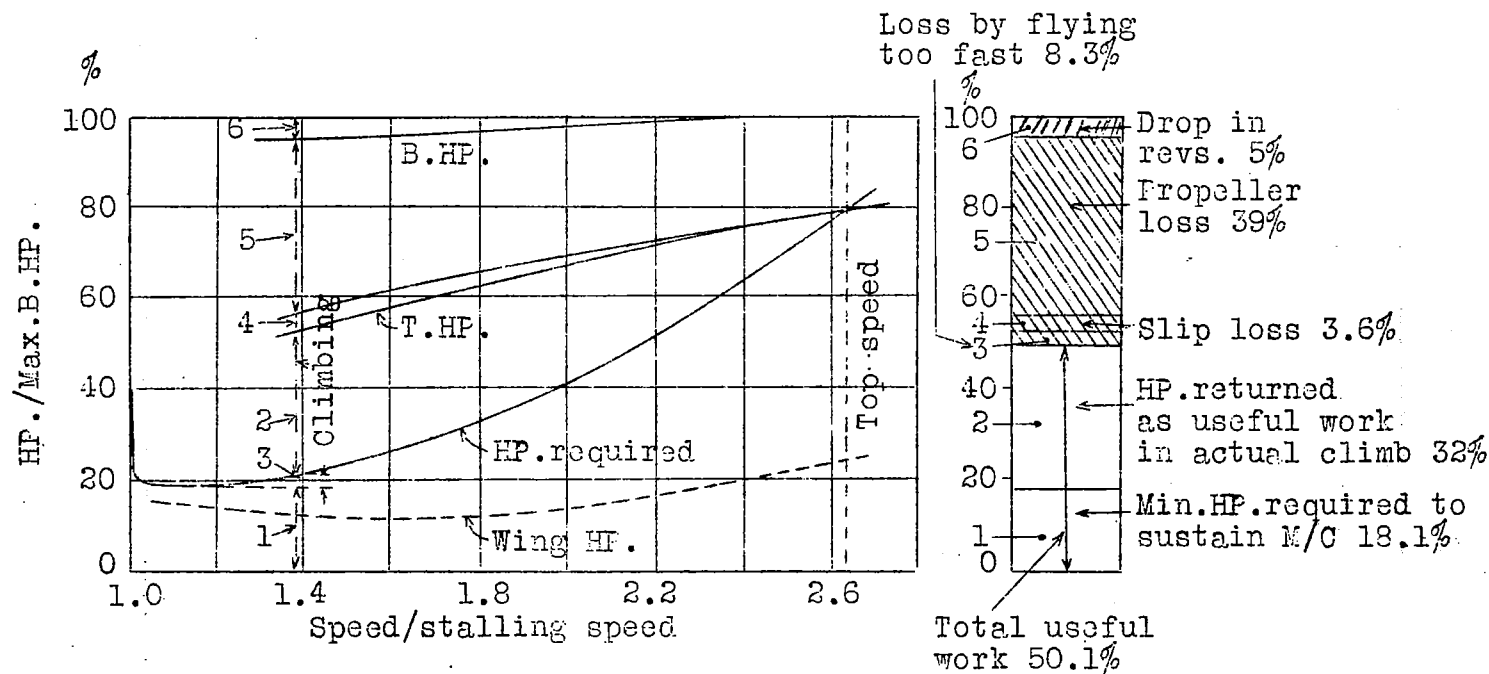


Fig. 3 HP. speed curve & power balance sheet, high performance single engine tractor biplane (land M/C) with direct drive water-cooled engine.

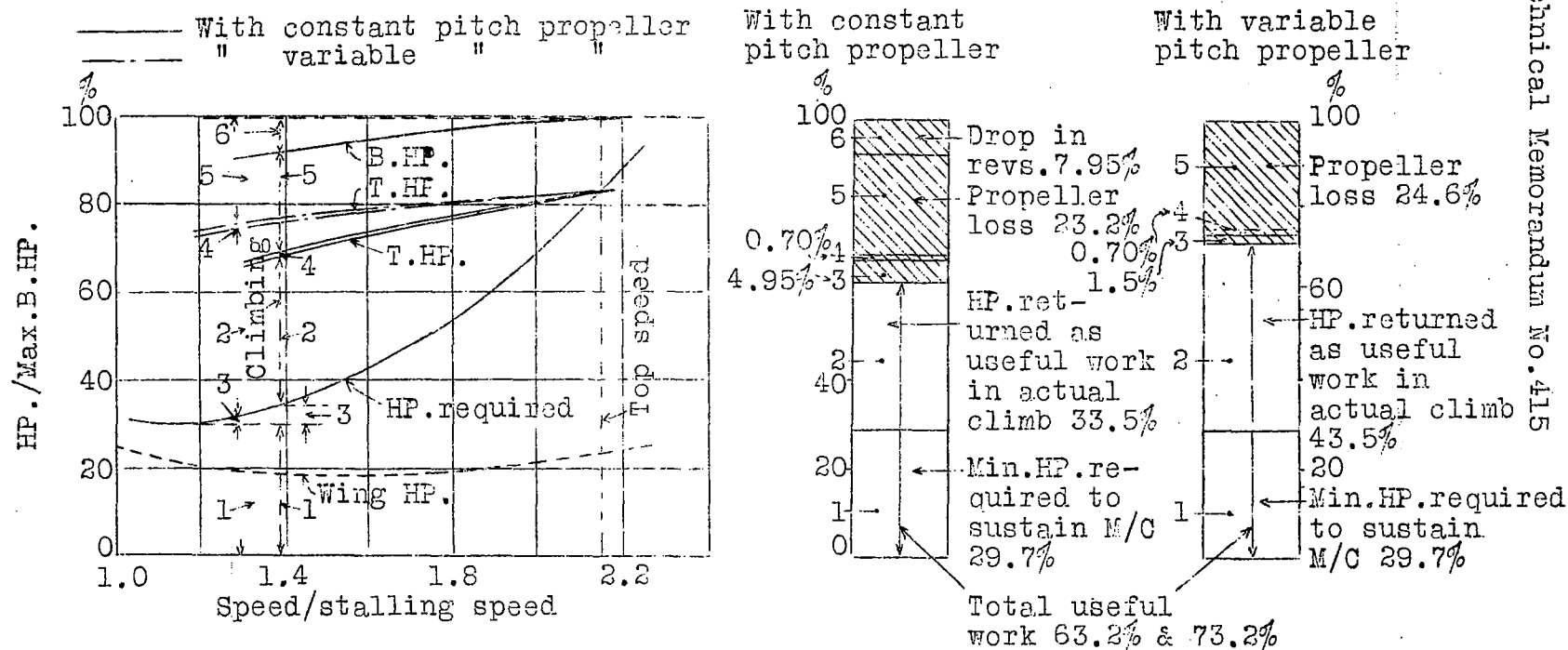


Fig. 4 HP. speed curves & power balance sheet, single engined tractor biplane (land M/C) with vee air-cooled geared engine, Effect of variable pitch propeller.

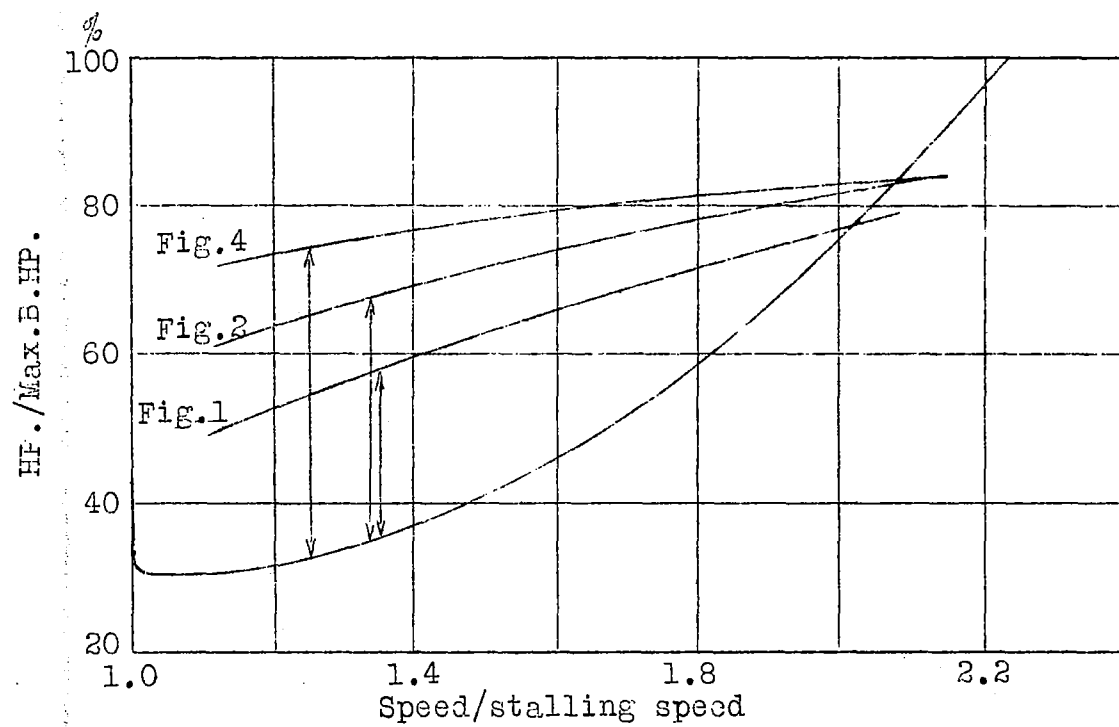


Fig.5